The Current Zoning Situation and its Seismic Resilience in Quito, Ecuador

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This study of zoning structures and effectiveness in Quito, Ecuador, addresses the readiness of the city to prepare for and ultimately respond to the events of seismic catastrophes. It was shown that Quito is at significant risk because of large-scale earthquakes, volcanic eruptions, mudslides and rockslides, and that it is crucial to examine how the city strategically utilizes its land for its respective purposes. A comparison between the current zoning situations of Quito and Santiago, Chile showed where Santiago produced a more advantageous disaster preparedness strategy than Quito, thereby indicating how Quito officials can address flaws and seize opportunities for improvement.

Keywords:

- *Quito, Ecuador*
- *Santiago, Chile*
- *Santiago Repopulation Program*
- *seismic catastrophes*
- *zoning situation*
- *Poverty Traps*
- *significant risk*
- *strategy*
- *implementation*
- *disaster preparedness*

Introduction

The city of Quito, Ecuador is one of the world's most susceptible cities to large-scale seismic activity. The South American city is home to approximately 2.6 million inhabitants and is the capital city of Ecuador.[1] However, Quito is only 105 miles inland from one of the world's most dangerous subduction zones.[2] The South American Plate, which is made up of principally less dense continental crust and includes the Andes Mountains, is bordered on the west by the Nazca Plate in the eastern Pacific Ocean.[2] Oceanic plates such as the Nazca are denser as well as older and cooler than continental plates.[2] As a result, the Nazca Plate passes underneath the South American Plate when the two formations collide with each other, as they constantly do.[2] Areas in which this geological phenomenon occurs are known as subduction zones.[2] Over time, subduction creates colossal mountain ranges, including the Andes in South America.[2] However, its side-effects include volcanoes, earthquakes, and tsunamis, some of enormous magnitude, as well as devastating landslides and mudslides that can result.[3]

Some of the world's largest cities are located in or quite close to subduction zones. A number of examples exist in South America including Concepción, Santiago, Antofagasta, Arequipa, Lima, Guayaquil, Quito, Cali, and Medellín.[4] It is understandable why so many of these cities are located on this boundary, though. When the expeditions of the Spanish Conquistadors started in the sixteenth century through the eighteenth century, the understanding of the theory of plate tectonics was nonexistent. The city of Quito had already been constructed by the native civilization that inhabited the land prior to the Incan Empire and Spanish conquistadors.[1]

These cities contain numerous volcanoes that make up the eastern boundary of the Ring of Fire.[2] These volcanoes were created by the subduction zone of the Nazca plate sliding under the South American plate, and the continental crust laying atop the submerging oceanic crust.[2] Further, earthquake intensities are found to be higher on the Richter Scale at convergent plate boundaries than at divergent plate boundaries, where two tectonic plates move away from each other, and at transform plate boundaries, in which tectonic plates slide past each other in opposite directions.[3] The city of Quito lies not only close to one of these convergent plate boundaries, but also in the Guayllabamba river basin.[5] This is vital to this study since having an understanding of the topography of Quito leads to a better analysis of the implications resulting from seismic

events. These include, but are not limited to, mudslides and landslides. Quito is also flanked by a series of active stratovolcanoes located in the Andes Mountain chain.[5]

Stratovolcanoes are volcanoes that are constructed from layers *(strata)* of lava, ash, and volcanic debris from previous eruptions.[6] Stratovolcanoes are powerful eruptions which result in significant hazards of volcanic ash, lava bombs, volcanic mudflows, pyroclastic flows and lava.[6 + 34] The active stratovolcanoes that cause significant threats to Quito include those of the Pichincha (bordering the city), Cotopaxi (75 km south of Quito), Cayambe (70 km northeast of Quito), and the Antisana (50 km southeast of Quito), Atacazo (25 km southwest of Quito).[7 + 28] Lava flows, ash falls and flows, mud flows (Lahars), volcanic landslides, tsunamis, and toxic gases are all potential consequences of an explosion from one of these volcanoes.[6] This hazard, in addition to the general significant seismic hazard presented by the subduction zone, underscores the need for effective zoning to ensure the protection of communities, and security of economic activity.

Quito's zoning code and its implementation are crucial to ensuring that the communities, individuals, and infrastructure of the metropolitan district of Quito (*Distrito Metropolitano de Quito*) can be kept intact and with minimal damage when calamities occur. This research will attempt to answer the question of, "How does the current zoning situation of Quito, Ecuador, help to mitigate and adapt to the consequences derived from high-level seismic disturbances hitting the metropolitan district of Quito?"

Though I was unable to access official building codes and zoning codes for the city of Quito, I was able to find numerous articles and literature that critiqued the implementation and enforcement of zoning and building codes in Quito. I found this to be even more helpful than the codes themselves as these codes are often not completely adhered to when dealing with unprecedented issues, such as Quito's extreme level of urbanization, and the extractive political and economic institutions that are present in Quito, as well. Using the information found in published studies, reports, books, and interviews, I developed a ranking system to compare my objective observations, relating to my research question, of the city of Quito to the city of Santiago, Chile. Santiago, Chile can be considered a regional "gold standard" in city planning for natural disaster mitigation and is therefore a great benchmarking candidate for this investigation. The variables chosen for this ranking system included: *Strength of Institutions*, *Severity of Urbanization*, *Current Zoning Situation*, and *Strength of Emergency Evacuation Plans*. A further

analysis of my reasoning for these variables is outlined in the *Recommendations* portion of this study.

Objectives

Zoning is defined as a legislative process that divides a jurisdiction or community into different zones with accordance to the specified land use.[8] Zoning is essential in natural disaster mitigation and response. This is because specified land use must be strategically planned in order to safeguard a city's infrastructure, economy, and inhabitants. This research aims to evaluate the effectiveness of the city of Quito's zoning situation, and the benefits and costs it creates for the economy, infrastructure, and regions. The goal for conducting this research is to highlight major issues with Quito's current zoning situation, and to offer recommendations for how the city can be more resilient in the face of these disasters. Quito, due to its physical geography, faces frequent and severe threats of earthquake activity, volcanic eruptions, landslides, and even tsunamis caused by the bordering plate tectonics. Zoning is vital since it is a key factor in determining the amount, and type of, damage to areas, communities and the overall economy of Quito. The objectives of this research are as follows:

- Compare the city of Quito's zoning situation, and its effectiveness for mitigating large-scale seismic disasters, with that of Santiago, Chile's (which can be regarded as the benchmark in effective zoning in South America).
- Create a ranking system to assign scores to each city to highlight the contrast of their current zoning situation.
- Research how urbanization and population growth lead to a comprehensive analysis of zoning needs, especially in a context where there is consistent seismic threat.
- Predict consequences of a large-scale seismic event on the city of Quito and examine zoning's effect on this.
- Offer recommendations for the city's zoning code, to help make the city more resilient in the future.

Figure 1: Seismic Risk of Ecuador[9]

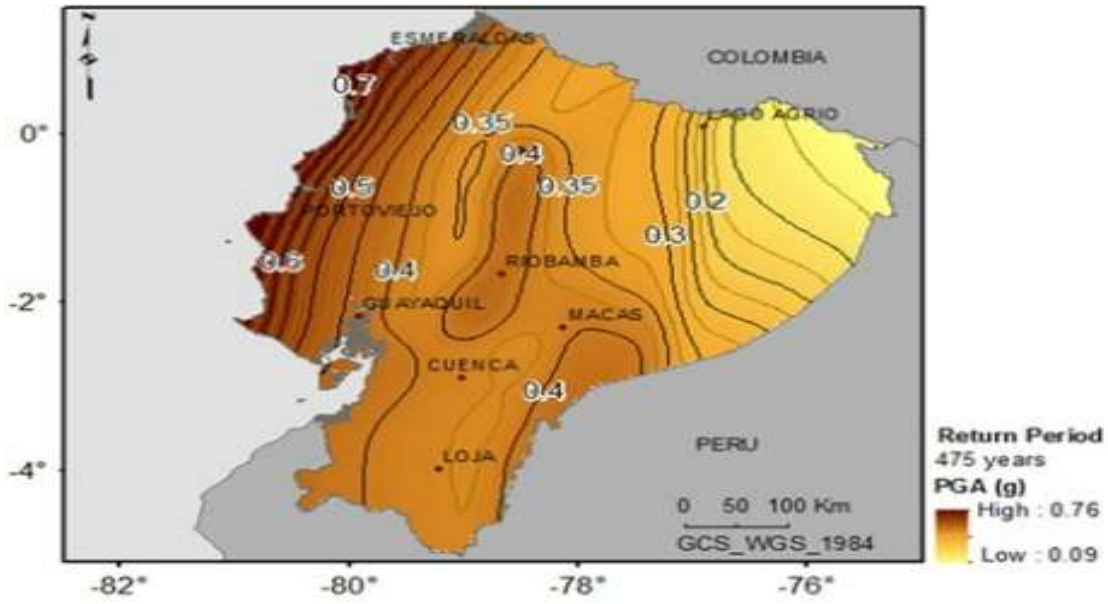


Figure 2: Faults and Damaging Earthquakes Over the Past Century Along the South American Subduction Zone[10]

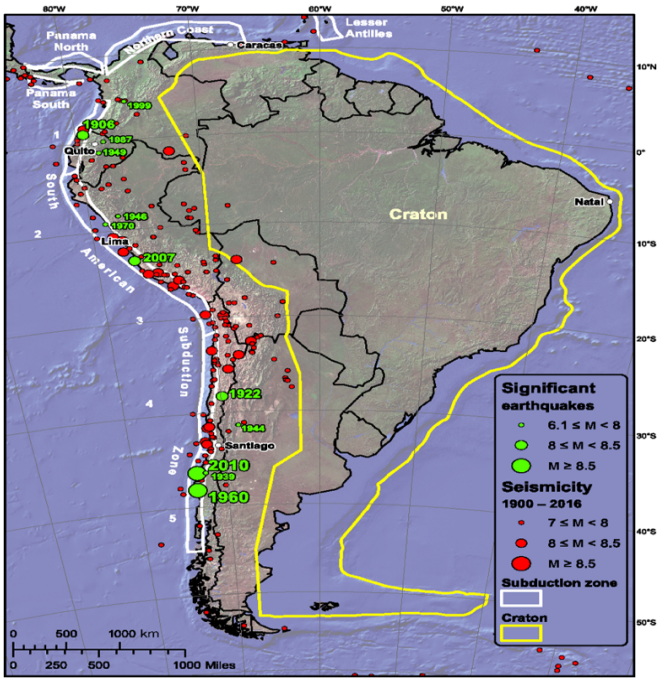


Figure 3: Earth's Tectonic Plates with Plate Movement Direction[11]

Methods

To fulfill these objectives, I read literature from academic journal platforms including: *JStor*, *Cambridge University Press,* and *WitStar.* I read published papers and lectures from universities including Yale University, The Ohio State University, and Harvard University. I also spoke with experts in Ecuadorian economic development, and with natural resource economists whose research focuses on Ecuador. Further, I used objective reasoning, critical analysis, and practical judgement in making recommendations, and to compare Quito's and Santiago's zoning situations for results.

I utilized objective reasoning by arriving at conclusions based on data observed from studies and overall statistics. From these facts, I was able to discuss these observations in analyzing their implications and consequences in the context of my study. This was key towards creating my variables of, *Strength of Institutions*, *Level of Urbanization*, *Current Zoning Situation*, and *Strength of Emergency Plans* in my Santiago and Quito comparison table (**Table 1)**. This led to using practical judgement, which I used when assigning a score to each variable in my comparison table for example, and when arriving at recommendations and conclusions made later in this study.

In terms of the academic literature utilized for this study, I reviewed seven published articles from universities such as Colgate University, Universidad Politéncia de Madrid, and Yale University. These articles were found from searches through google scholar, with key words and phrases such as, *seismic risk Quito, Ecuador*, *Zoning situation Quito, Ecuador*, *Tectonic Movement Earthquake*, and *Quito Urban Growth*.

Interviews were also conducted as part of this research. Over the course of working on this analysis, I interviewed Dr. Douglas Southgate from The Ohio State University on multiple occasions. These in-person interviews were focused on the problems Quito has faced and currently faces in terms of its political and economic institutions that can exacerbate current urban planning problems and inhibit sustainable development. We also discussed what problems urbanization and the political landscape has on a possible re-structuring of zoning for the city. I also had e-mail conversations with Dr. Fabían Rodríguez of Universidad de las Fuerzas Armadas. With Dr. Rodríguez, an expert in natural resource economics and a former student of

Dr. Southgate, we discussed the current economy of Ecuador, and its susceptibility to a poverty trap discussed later.

Lastly, lectures from an introductory geology course taught by Dr. David Young at The Ohio State University provided relevant natural science content that was heavily used throughout my research. Material from lectures from an economic development of Latin America course was also heavily relevant and useful when conducting research on political and economic institutions of Ecuador, that inhibit or spur sustainable development and zoning re-structuring programs.

Implications

Santiago and Quito share a geographical similarity in that both cities are situated in closed basins surrounded by the Andes Mountains.[12] However, socioeconomically, Santiago is based in the wealthier nation of Chile, and Quito in the poorer country of Ecuador.[13] The GDP, in current US Dollars of Chile was recorded at approximately $277.1 billion dollars (2017) whereas the GDP of Ecuador in 2017 was less than half of Chile's at approximately $103.1 billion dollars (2017).[13] Per capita, the GDP of Chile was recorded at $15,346 US dollars (2017) and Ecuador's GDP per capita was recorded at $6,273 (2017).[13] Nevertheless, Ecuador's GDP is growing at a faster annual rate than that of Chile's, at 2.37% compared to 1.49%, respectively, in 2017.[13] The GDP of these countries is extremely important as it helps determine funding that can be allocated towards disaster mitigation efforts, rezoning, improvements of infrastructure, and emergency evacuation plans, among numerous other measurables.

Santiago is unfamiliar with significant seismic activity. Yet, in the wake of the 9.5-magnitude Valdivia Earthquake, which struck on May 22, 1960, Santiago upgraded its building codes, zoning regulations, and incorporated numerous additional improvements towards disaster-mitigation efforts.[14] As previously mentioned, Santiago can be considered to be a "Gold-Standard" of infrastructure and zoning policy in South America.[15] Among significant development since 1960, after the Valdivia Earthquake which was the largest earthquake ever recorded on seismographs, is the Santiago's Repopulation Program (SRP) which was initiated in 1990 due to the political and economic climate after the Pinochet regime.[16] The SRP was a

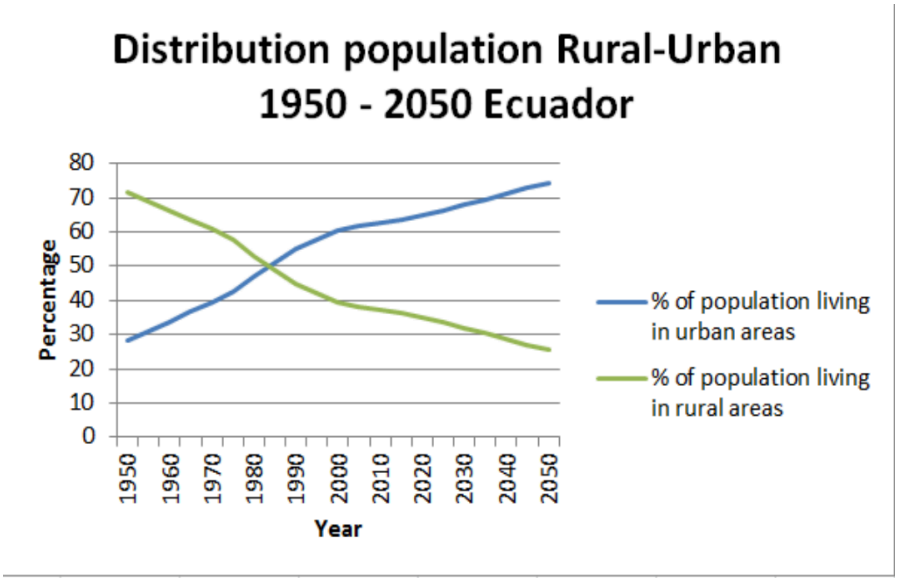
strategy for urban regeneration after many decades of urban decay in Santiago's municipal district (SMD).[16] It has been widely successful, and boosted interest within the private sector for cooperation with the government for the sake of sustainably addressing Santiago's urban planning and zoning needs.[16] Since 1990, the plan has been modified 29 times to adjust to the urban conditions that Santiago faced during this time frame, most notably to help distribute the density of development.[16] Increasing civilian security, especially through addressing housing needs and environmental protection, have been two of the largest contributing factors towards this plan's modification history.[16] Because of the boost in investment into the city from the SRPs plan to address zoning, among other urban planning-related issues, the financial outcomes of Santiago's renovation have been substantial. In fact, from 2001-2013, the total municipal revenues of Santiago increased over 55%.[16]

Quito faces a very similar seismic-issue with Santiago. The major seismic threat to Quito comes from earthquakes that occur regularly near the inter-Andean valley where the city is located.[17] In fact, in the last 460 years of Quito's history since the Spanish Conquest, the city has experienced seismic intensities greater than or equal to 6 MMI (Modified Mercalli Intensity) on at least 23 recorded occasions.[17] Therefore, solely from an investigative standpoint on seismic intensities, Quito has significant need for a zoning analysis to determine if the city's current land-use structure ought to be changed.

Rapid urbanization is another problem Quito must endure. From 1950 to 1990, Quito's population multiplied six-fold, and the surrounding peripheries of the city, which include minor urban areas, grew twenty-fold.[26] Between 2000-2013, Quito had an annual growth rate of 3.2%, which compared to the 0.76% growth rate of Santiago, Chile, this urbanization growth rate is far higher.[32+33] The attempts to regulate this growth, though, have proven to be unsuccessful.[26] Efforts to incorporate urban growth boundaries and decentralization of management powers resulted in failure.[26] This population boom is the consequence of Quito's capacity to provide people with jobs and overall better livelihoods.[26] Nevertheless, management agencies, communities, and the local government of Quito understand that urban growth occurring at a near uncontrolled pace has significant negative impacts, including: water quality and availability, needs for improved infrastructure, lack of green and natural spaces, heightened air pollution/decrease in air quality, and congestion. Explosive recent growth of the city has resulted in a boom in residential zoning of Quito, expanding the cities prior residential areas to

incorporate further areas in the inter-Andean valley, and only adds to the severity of impending situations involving seismic catastrophe in Quito.[18] A significant proportion of residents coming into Quito are establishing informal settlements located mostly in hazardous areas prone to floods and landslides.[18] These landslides can become highly problematic to those living in these areas in the case of a large-scale seismic event.

Figure 4: Rural-Urban Ecuadorian Population Trends, 1950-2050[18]



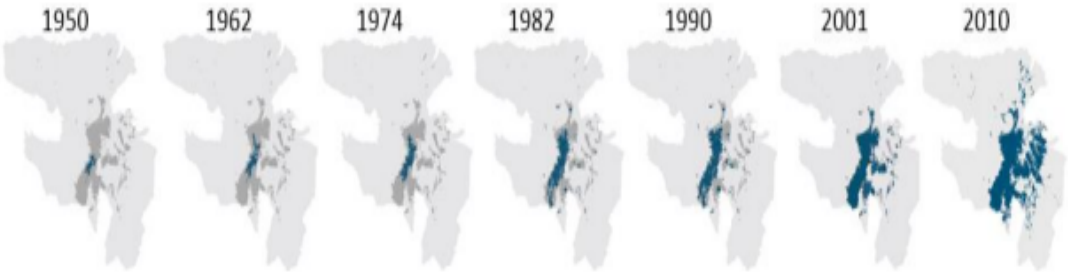
Because of a lack of proper zoning for residential areas in Quito, the city created a plan to construct buildings at an extremely rapid pace, prioritizing quantity over quality. [17] This caused these buildings to be poorly located and even poorer in their construction. [17] Building codes were overlooked in this effort to construct as many buildings to support the growth. [17] The efforts to accommodate the explosive growth of the city has resulted in structures being built on unstable sites such as *quebradas* (ravines) that are located on steep hillsides filled with loose soil. [17] Buildings of this sort place much of the population in the inter-Andean valley at considerable peril.[17]

Both Quito and Santiago are two of the most susceptible South American cities to significant seismic activity but are not equally prepared for earthquakes and volcanoes. Quito does not have the same caliber of evacuation policies nor plans that Santiago has.[16] With the onset of further urban growth expanding housing beyond areas that are strictly zoned and

regulated for residential development, the chances for greater casualties of communities increases. This is the case in the outskirts of Pichincha volcano. After a seismic event, evacuation from such areas would be difficult not only due to the problem of congestion but also due to the problem of poorly constructed roads, bridges, buildings, and the possibility of infringed water and electricity routes.

Presently, Quito does not have a high-caliber zoning ordinance situation. Quito has grown at an accelerated rate, as shown by the graph in **Figure 5,** and the government of Ecuador has had difficulty to implement means to confront social and economic development in order to provide adequate disaster relief mitigation efforts and infrastructure needs. **Figure 5** highlights the Pichincha Province in light grey, the 2010 boundary of Quito in dark grey, and the blue represents how the city has expanded to its 2010 urban growth boundary from 1950 onward.

Figure 5: Growth of Quito 1950-2010[19]



In addition, sustained migration is a contributing factor to Quito's rapid urbanization, and the city is considered to be a major migrant destination of South America. This is in large part due to the concentration of commercial and professional activities offering a large market to enterprises.[19] Quito therefore contains an expanding and concentrated population, and between Quito, Guayaquil (Ecuador's largest city) and other urban centers in Ecuador, the urban population has increased steadily from 30.8% in 1955 to over 64.8% in 2018.[20] In accordance with the United Nations Department of Economic and Social Affairs (UNDESA) Quito will experience population growth and urbanization until 2040 of about 33,800 persons

per year, due to Ecuador's fertility rate of 2.5 births per woman, higher than the replacement rate of 2.1 births per woman, mortality rate of 5.1 per 1,000 people, slightly lower than the global average, and simultaneous increased migration to Quito.[19 + 35]

With the growth of this population in urban centers of Ecuador, the municipal government defined a set of public policy guidelines in the "Quito 21st Century Plan" *(Plan Quito Siglo XXI)*.[21] This plan is centered on Quito's development as an area for welfare and solidarity for all, environmental and aesthetic qualities, but most relevantly that it will show security when faced by natural and human hazards.[21] This includes a review of their disaster mitigation plans and the maturation of efficient evacuation plans when natural disaster hits.[21] However, these plans are not being implemented in Quito to adequate standards of efficiency.[21] The primary cause of its struggle towards implementation is significantly due to corrupt and extractive institutions in the economic and political sectors of Ecuador.[21] The government is attempting to address this problem by promoting the urbanization of intermediate sized cities in an effort to decrease the level of urban growth flooding into Quito.[21] Nevertheless, the pace at which Ecuador's urban areas are growing is creating numerous challenges for these intermediate cities that are insufficiently prepared to accept tens of thousands of new citizens on an annual basis.[22] Consequences of this rapid urban growth include high resource consumption, CO2 emissions, congestion, social inequality, and additional destructiveness in the face of seismic catastrophe.[22] In addition, these cities are expanding to further distances on rural areas destroying farmland and harming the environment.[22]

This resulting action by the city of Quito, specifically the Quito 21st Century Plan, is a step in the right direction but not a comprehensive solution. The principal critique of this action taken by the government of Ecuador is that the suburban and intermediately sized urban centers of Ecuador do not have urban services and employment opportunities nearly on the scale of Quito's.[22] This policy action leads to increased congestion in the city of Quito, which increases the risk even further of casualties if a natural disaster were to hit. This action of encouraging growth towards Ecuador's medium sized cities addresses the issue of the lack of housing, resulting in overcrowded living areas with many informal illicit settlements appearing in Quito. However, there is a continued increase of people living in hazardous

areas prone to natural disasters, especially of the secondary effects once an earthquake or volcanic eruption strikes.

Additionally, insufficient infrastructure for sewage, water, and solid waste disposal pose another key problem for the city. This is especially true for the secondary effects of natural disasters. Gas and water pipes run underneath the city, and so if a sizeable earthquake hits, Quito becomes far more susceptible to gas leaks that can result in extensive fires. Further, water pipes are also quite vulnerable which would make the quelling of a possible fire far more difficult. This would greatly affect a substantial proportion of Quito's population since 53% of the settlements found in Quito, in 2011, were informal and were of slum-like nature.[18]

Another reason why Quito does not have a sufficient zoning structure that can help to mitigate the consequences of a large-scale seismic event is because Quito has a relatively unstable economic and political situation. Ecuador is considered to be entangled in "Poverty Traps" that inhibit Quito, and the nation of Ecuador as a whole, from sustainable development due to the extractive political and economic institutions.[23] According to British professor and economist, Paul Collier in his book *The Bottom Billion*, Ecuador is currently caught in two development traps that prevent Quito from reaching sustainable development.[23] The economy of Ecuador is not suited for sustainable development because of its heavy concentration in commodities traded on the global market making it quite susceptible to "Dutch Disease" or the natural resource boom or bust.[23] If the prices of oil, bananas, and shrimp, which are the three largest elements of Ecuador's economy rise, then the economy of Ecuador consequently rises quite proportionally, and if these commodities become cheaper, then the economy dips.[23] Chile's economy, though is quite heavily involved with the mining of minerals and metals, has gone through significant diversification.[31] Chile also greatly respects real and intellectual property rights, and courts generally enforce property and contractual rights free from political interference.[30]

The second development trap that Ecuador is in is the lack of governance trap. According to the global coalition against corruption, which releases a *Corruption Perceptions Index* on an annual basis, Ecuador ranked 114th in the world in its corruption score, tying with Ethiopia and Niger.[29] This is one of the poorer scores for a Latin American country, as well, as Ecuador ranked as the 20th out of 29th most corrupt Latin American country.[29] Conversely,

Chile scored an overall transparency ranking of 27th best in the world, and 3rd best in Latin America.[29] Compared to Ecuador, the situation in Ecuador is worse in the economic and political sectors-to help direct funding towards natural disaster relief efforts. A lack of governance and/or corruption can directly hinder zoning re-structuring since funding that was originally designed for specific programs and plans to help confront zoning issues can be redirected to other programs that could be more beneficial to a politician, or even to pockets of corrupt government officials.

Figure 6: Quito Seismic Zones and Distribution of Intensities for Local Earthquake Scenarios, Measured on the Medvedev-Sponheuer-Karnik Scale (MSK)[24]

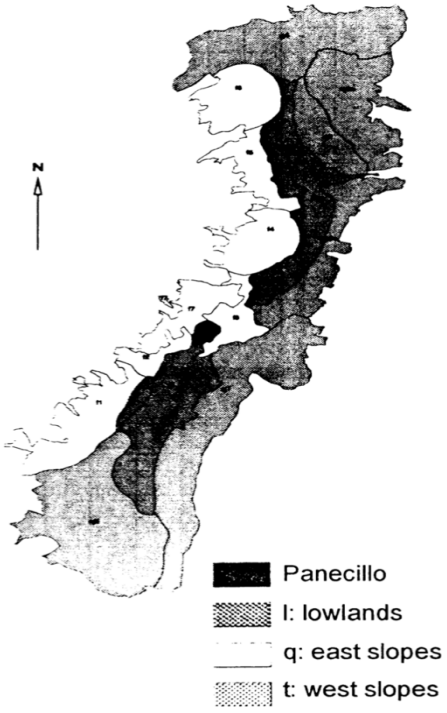


Figure 3: Seismic zones for Quito.

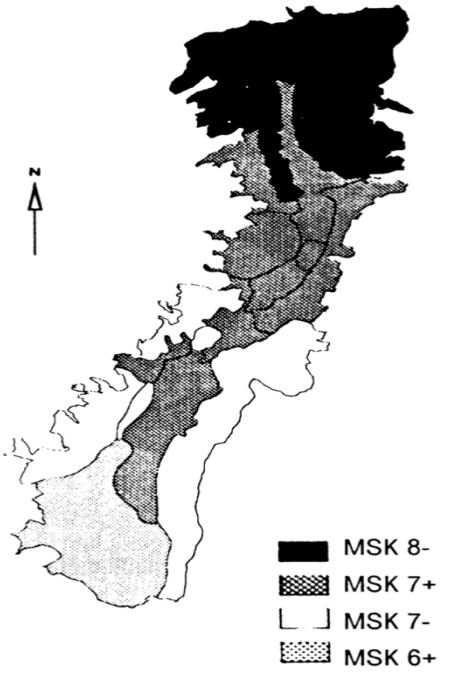
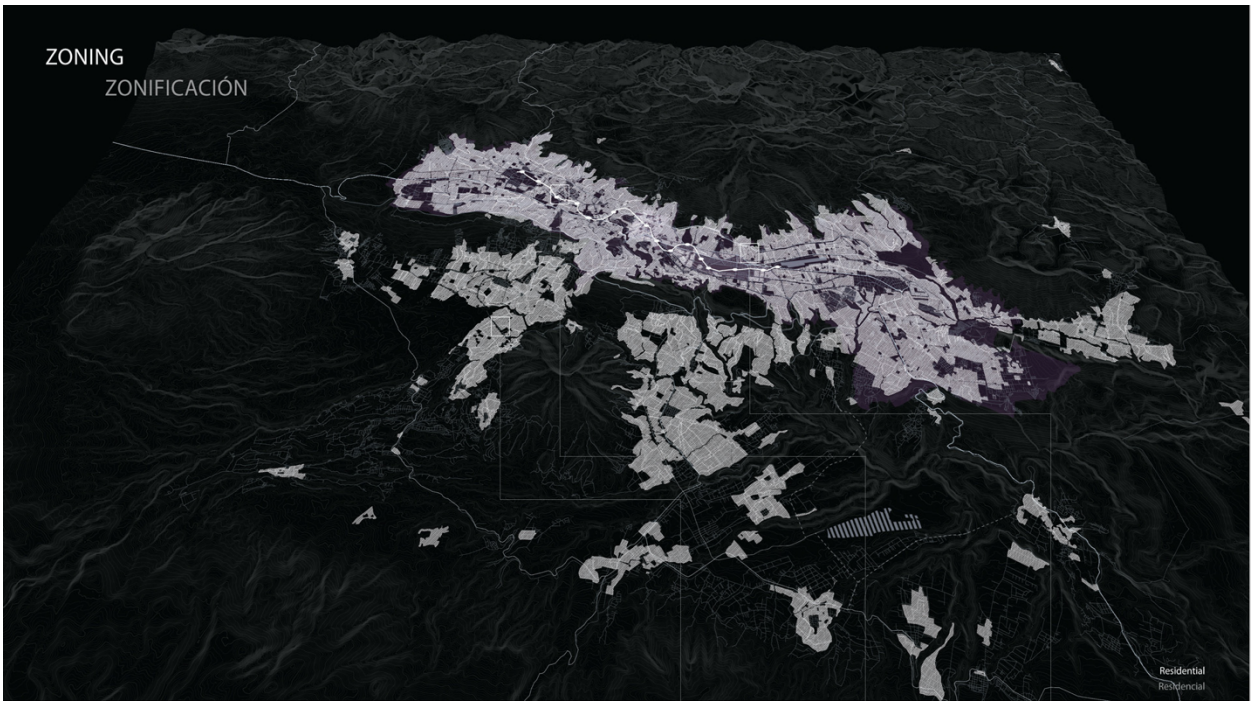
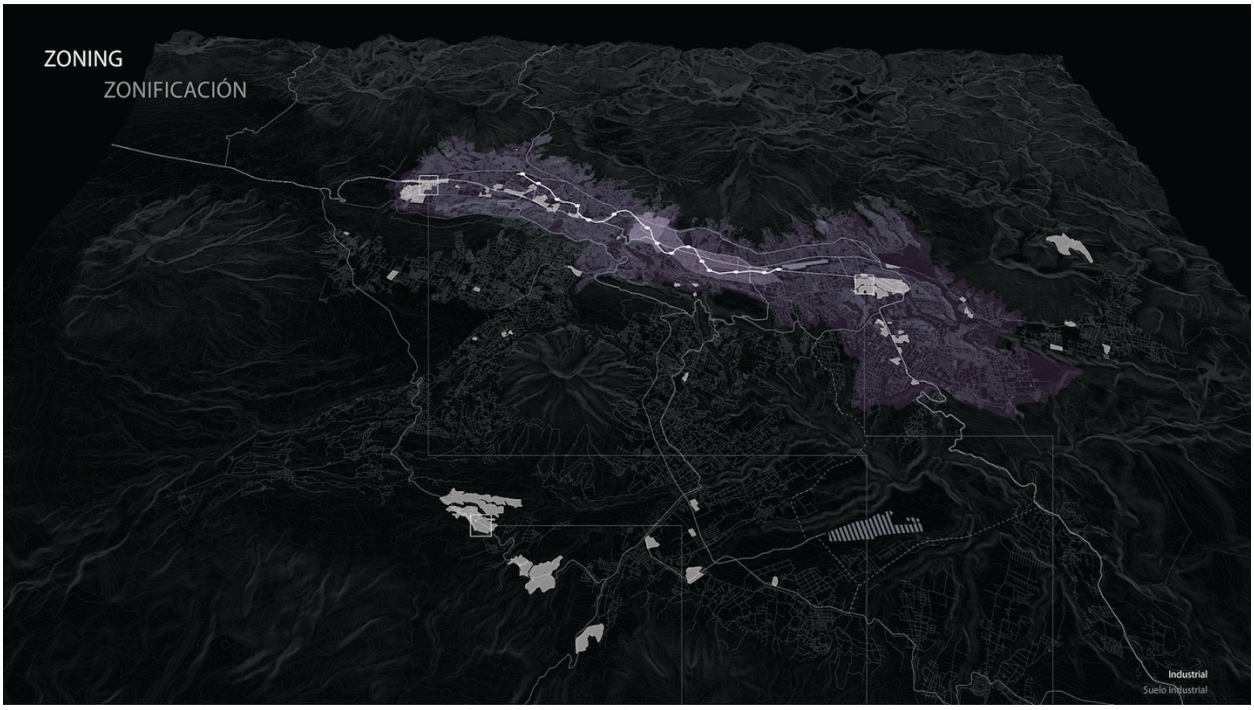


Figure 4: Distribution of intensities in Quito for local scenario earthquake.

Figure 6: (6-Top) GIS-Constructed Map of Quito's Residential Areas (Light Purple) & Figure 7: (7-Bottom) Industrial Areas Showed (in Light Grey)[25]





Recommendations

My principle recommendation for the city of Quito is that the city needs to expand its residential zoning away from the inter-Andean valley, and instead to the outside bases of the mountains that border it. This is not only due to the fact that most seismic activity occurs in the valley, but also because it has been shown that earthquakes can trigger volcanic eruptions, in which case it would be best to live outside the volcanic-surrounding valley. Instead, Quito ought to direct new residential construction toward the southwestern and southern parts of the city (where risk of both earthquake and volcanic activity is lowest) while upgrading the existing building structures of the primarily working-class southern region of the city. Nevertheless, this is not a one-problem fix-all situation as changes in zoning often lead to new issues. For example, new residential development should not harm the ecological reserve, Los Ilinizas, which exists south of the city.

Quito should look to create a program similar to Chile's SRP and consider moving its industrial and commercial activities towards the western slopes of the city, where earthquake intensity is lower than in the lowlands where much of that activity is currently located in. Lastly, emergency plans and remedial measures must be implemented, and considered a priority of the government of Ecuador. Though development traps will continue to play a role to inhibit the sustainable development of Quito, and Ecuador as a whole, regional progress has been generally consistent in Ecuador. Quito will be moving towards the path of improving its current zoning situation to that of Santiago's, and the results of Santiago's modern zoning implementation effectiveness depicts why the city's resilience to large-scale seismic disasters is far greater than that of Quito's.

To create a more comprehensive picture of the comparison between Santiago, Chile's zoning situation and that of Quito, Ecuador's, I have created a ranking chart to assign each of these cities a score. Each city will receive a score based on a scale of 0-10, with 0 being the worst zoning situation, and 10 being the most ideal zoning situation to mitigate seismic catastrophe. Each category/variable has an equal weight which will be used in determining a

total score and the eventual cumulative score to compare these cities to. The information for this table can be found in Table 1.

Table 1: Comparison Table of the Current Zoning Situations in Quito and Santiago

City	Variable	Total Score (0 - 10, worse to better)
Quito	Strength of Institutions	3
	Severity of Urbanization	2
	Current Zoning Situation	3
	Strength of Emergency Evacuation Plans	2
Santiago	Strength of Institutions	8
	Severity of Urbanization	4
	Current Zoning Situation	7
	Strength of Emergency Evacuation Plans	9

From this table, Quito averaged to a cumulative score of 2.5, and Santiago received an averaged cumulative score of 7. Therefore, it would serve Quito extremely well to review methods to advance their current structures impacting zoning, in a direction towards the structures of Santiago.

I chose the variables of *Strength of Institutions*, *Severity of Urbanization*, *Current Zoning Situation*, and *Strength of Emergency Plans* to construct this table. Strength of institutions was chosen as a variable as this will be a direct determinant of if, and to what extent, funding can go to programs that work on solutions concerning seismic mitigation through zoning re-structuring. Severity of urbanization was chosen as this variable impacts the potential for not only more casualties due to congestion and a larger amount of people living in these cities, but also more damage to infrastructure, buildings, houses, communities, and overall livelihoods. The current zoning situation was assessed to determine how effective the zoning structure is, and would be, at mitigating the consequences of seismic disasters. Strength of emergency plans was included, lastly, since emergency evacuation planning ought to be a principal concern and ought to be considered when investigating zoning structures and how they can be changed to help these emergency evacuation efforts.

Conclusion

This study is not only applicable to Ecuador, or Latin America in whole, but is suitable to examine current zoning situations in every city or region in the world. It is clear that zoning plays a significant role when it comes to mitigating the consequences of potential natural disasters. The recent Kilauea eruption in Hawaii sparked a debate concerning Hawaii's current land-use and zoning regulations, to see what changes ought to be made in order to ensure reduced costs. The devastating Hurricane Katrina of 2005, and subsequent destructive hurricanes, and other natural disasters, shed light on the issue of emergency evacuations, and how to best prepare to mitigate against natural disasters that may or may not be seismic in nature. Regional zoning is integral to the protection of communities, economies, livelihoods, and the role in which cities play for its inhabitants and the global community.

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